

Recycling Infrastructure for Engineering Thermoplastics: A Supply Chain Analysis

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A&B Recycling Inc.
Advanced Recovery
American Plastics Council
American Reclamation Corporation
Apple Computer, Inc.
Bayer Corporation
Berman's Diversified Industries Inc.
Butler MacDonald, Inc.
Chi Li Plastics
Compaq Computer Corporation
Compaq Services
Conigliaro Industries
Dell Computer Corporation
DMC
Dow Chemical
Draper & Lennon, Inc.
Ecobalance
Envirocycle, Inc.
EPA Inc.
Ford Motor Co.
Fortune Metals and Plastic
Gianco Ltd.
Great Lakes Chemical
Hewlett Packard Company
IBM Corporation
Kaiser Overseas
Lucent Technologies
MA Hanna

Marsh Plastics
Matsushita Electric Corporation
Michael Day Enterprises
MRC Polymers
MBA Polymers Inc.
Micro Metallics Corporation
NEC Technologies
New Jersey Institute of Technology
Nypro Inc.
Oriental Export
The Plactory
The Plastics Group of America
Plastic Resale Corp.
Pitney Bowes
R Frazier US, Inc.
RC Plastics
Recycling Separation Technologies, Inc.
ReVamp Inc.
SelecTech, Inc.
Sun Valley Recycling
Trotter Technologies
University of Massachusetts Lowell, Institute for
Plastics Innovation
Vista Environmental
Wellman, Inc.
Wilsonart International
Xerox Corporation

Abstract

Several years ago, the electronics supply chain was making substantive progress in establishing programs and partnerships to demonstrate the recovery, identification and sorting of plastic from electronic equipment; and making inroads in the design community to gain acceptance of recycled-content resins in new products. Many of these entrepreneurial efforts hit major roadblocks due to the lack of consistent, quality supply and insufficient demand. Technology is no longer the major challenge. Recyclers and equipment manufacturers have demonstrated recovery processes that achieve high quality recyclate that can even meet the demanding specifications for cosmetic parts in electronic applications. Industry now faces the economic, institutional and political realities of making plastics recycling work.

I. Background

Recycling of electronic equipment is on the rise in the United States, fueled by international and US regulatory developments and heightened interest in managing both the asset value and waste stream created by the growing use of electronic equipment. Waste management objectives target both the hazardous constituents in electronic waste and waste diversion goals.

Electronic product recovery and recycling directives have been on the international agenda for several years, most notably in Europe and Asia. In 1998, the European Union raised the stakes with its draft proposal on electronic waste with stipulations on new product design, including restrictions on the use of heavy metals and requirements for the use of recycled plastic in new products. This directive is certain to have a "ripple effect" in the US. At the same time, regulatory activity in the US has picked up with several states actively pursuing electronic waste policies. Most notably, a ban on the disposal of cathode ray tubes (CRTs) is slated to take effect July 1, 1999 in Massachusetts.

Electronics recycling creates a new and growing plastics waste stream. As shown in Table 1, plastics in electronic equipment range from approximately 10 to 50 percent of materials by weight. [1] Of the materials found in electronics, plastics have the highest intrinsic value, according to several analyses. [2][3] Despite their prevalence in the electronics waste stream and their inherent value, however, plastics are the least recycled material.

This study addresses the recycling of engineering thermoplastics (ETPs) in electronics. It analyzes the dynamics of the plastics and electronics supply chain to identify successes, barriers, and opportunities in plastics recycling and use of recycled content in electronic equipment, with a focus on computers. The purpose of the research is to illustrate the potential for voluntary cooperation among companies in the supply chain to recover and recycle engineering thermoplastics in lieu of mandated producer responsibility.

This analysis is based on interviews with over 50 companies in the supply chain, including resin suppliers, compounders, molders, equipment manufacturers, electronics recyclers, plastics processors, and end use markets, in addition to available literature and electronic data. Figure 1 provides a schematic of the supply chain. Interviews were conducted between November 1997 and November 1998. Participating companies are listed in the Acknowledgements.

II. Extended Product Responsibility in the US

Extended product responsibility (EPR) is an emerging principle for pollution prevention in which the key players in the chain of commerce take appropriate responsibility for the environmental impacts of the product throughout the lifecycle, including upstream impacts associated with material selection and product design and downstream product disposal and recycling. Ideally, EPR results in the sharing of responsibility for ameliorating environmental impact among material suppliers, product manufacturers, distributors, users, recyclers, and

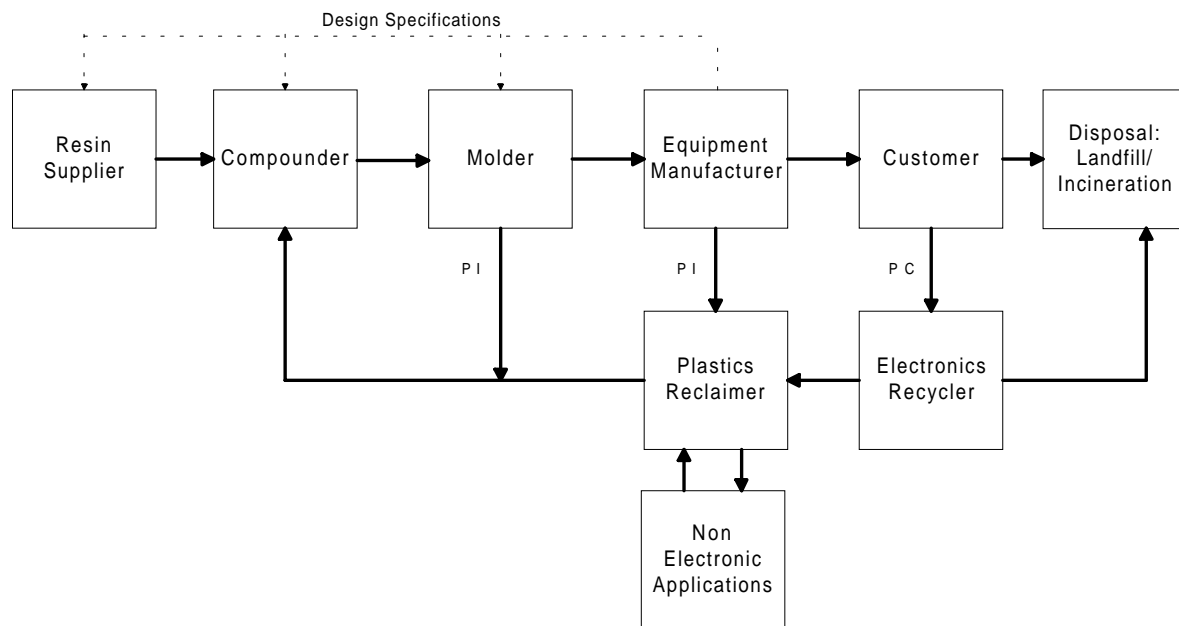


Figure 1: Supply Chain for Electronic Engineering Thermoplastics

disposers, with the greater degree of responsibility resting with those actors in the product chain most able to influence environmental impacts cost-effectively. EPR can be applied by industry voluntarily or influenced by government requirements (e.g., purchasing preferences, product take-back mandates.) [4]

In its 1996 report, *Sustainable America*, the President's Council for Sustainable Development (PCSD) endorsed the principle of extended product responsibility as a means to "identify strategic opportunities for pollution prevention and resource conservation" throughout the life cycle of a product. US EPA is encouraging **voluntary, shared responsibility** within the product chain as an alternative to "extended **producer** responsibility". Extended producer responsibility, as currently applied to a variety of products in Europe and Asia, **mandates the central involvement and financial responsibility of producers in non-traditional functions**, such as the collection and recycling of electronics. While other links in the product chain, such as retailers, may also be required to accept new responsibilities, the greatest responsibility, as well as accountability, lies with producers.

Although EPA has not embraced "Euro-style" producer responsibility, it shares many of the same goals, as defined by the Organisation for Economic Co-operation Development (OECD):

- to reduce waste generation and increase recycling;
- to reduce the financial burden of local governments for waste management; and
- to give incentives to producers to design and manufacture products that result in less waste and are more recyclable.[5]

In contrast to producer responsibility, EPA believes in shared responsibility that places greater -- but not sole -- responsibility on producers. For example, product design and creating markets are clearly within the purview of producers. EPA also seeks voluntary efforts, not mandates. Voluntary initiatives would seek to tailor solutions based on an understanding of the unique attributes of a product system, and engage the supply chain in collaborative solutions spurred by "enlightened self interest". Benefits to the supply chain might include lower costs, procurement preferences, preemption of mandates, and harmonization across states. [5]

III. Plastics Use in Electronics

Worldwide resin sales to the electronics industry generated \$933 billion in revenues for the plastics industry in 1996. Sales are expected to increase by over 40 percent in 1999. [6] In 1996 the US electrical and electronic industry consumed over 3 billion pounds of plastic, or 4.0 percent of the total plastics consumed in the US. [7] Within the electronics industry, the computer and communications markets consumed the highest volume of resins. [6]

On average, plastics account for approximately 19 percent (by weight) of electrical and electronic (E&E) equipment. [1] Table 1 provides a breakdown of the average plastic content of E&E equipment in Western Europe in 1995. Several pilot municipal collection programs in the US documented the proportion of plastics in the residential electronics waste stream at 33 percent for diverse electronic equipment [8] and 16 percent for computer equipment. [9]

Table 1: Average Plastic Content of E&E Equipment Western Europe 1995 [1]

Equipment	% Plastic
Telecommunications	58%
Small Appliances	35%
Brown Goods	26%
Wire and Cable	25%
Large Appliances	21%
Computers	16%
Office Equipment	11%
Medical Equipment	3%

Table 2 shows the breakdown of resins used in E&E markets in North America. These six resins and their blends account for 84 percent of total resin consumption in E&E equipment, not including cable and wire. [10] The major resins used in the manufacture of computer and electronic housings, include: acrylonitrile butadiene styrene (ABS), ABS/polycarbonate (PC) blends, high impact polystyrene (HIPS), polycarbonate (PC), polyvinylchloride (PVC), and polyphenylene oxide (PPO). Fire retardant grades are used in some applications.

Table 2: Resins in E&E Equipment in NA [10]

Resin	% Total Resin
Polystyrene	31%
ABS	16%
Polypropylene	13%
Polyurethane	10%
Polycarbonate	9%
Polyamide	5%

Manufacturers choose specific resins to meet product performance requirements such as impact strength, thermal stability, shock absorption, aesthetics, flame retardancy and costs. Resin usage changes over time with product mix (e.g., mainframes to desktop to portable computers), technology innovation (e.g., thin wall technology), the introduction of new resin blends, and, in some cases, requirements of standards organizations (e.g., flame retardancy). One major computer manufacturer, for example, uses polycarbonate in portable products for its durability, while using PC/ABS in desktop models.

Current trends in resin use will impact end of life equipment recycling in 8-10 years, and the potential for reintroduction of recyclate into new equipment. For example, in this increasingly competitive industry, OEMs are choosing lower cost resins, where possible. One trend is in the replacement of ABS with HIPS, a lower cost resin. HIPS has traditionally been the material of choice for television housings, but currently it is eroding the market for ABS in business machines. [11] Pressures to eliminate halogenated flame retardants and design products for recycling have led to the use of metal shieldings in computer housings. This allows OEMs to shift from ABS/PC, which is free of halogenated flame retardants, to lower cost ABS and HIPS.

IV. Supply Chain Analysis

Prior research indicated that industry was making substantive progress in establishing new programs to demonstrate the recovery, identification and sorting of plastic casings from computers housings, photocopiers, and other office equipment; and making inroads in the design community to gain acceptance of recycled-content resins in new product. [4][12] When companies in the plastics supply chain were approached for this project, it came as quite a surprise to learn that many of the entrepreneurial efforts had hit major roadblocks and fizzled out, or that the companies decided for various reasons not to pursue plastics recycling.

Below is a brief summary and observations on the initiatives taken by the supply chain to recycle engineering thermoplastics, and incorporate recycled content into new product.

A. Resin Suppliers

Resin suppliers were involved early on in the promotion of recycled resins, then backed off due to lack of sufficient demand from OEMs, supply issues and business priorities. Several suppliers continue to offer limited selection of recycled-content products in some markets.

Major prime resin suppliers in the US did not witness a strong, persistent market demand for recycled resins to warrant investments in developing this business. OEMs expressed interest to resin suppliers, but only if recycled resins could provide significant cost savings compared to virgin without compromising quality. For the most part, resin suppliers could not (or were not willing to invest the resources) to meet these requirements.

Resin suppliers are invested in prime production and feedstreams. Prime resin is there core business. Recycled resin products represent a new business and a challenge to develop new sourcing channels that provide consistent, quality product to customers. In addition, some resin suppliers question whether it makes sense for them to be in the recycled resin business.

Through organizations such as the American Plastics Council (APC), prime resin suppliers have been instrumental in the development of technologies for the identification and sorting of plastics, and thus, helping to build a recycling infrastructure.

B. Compounders

Several specialty compounders (or second tier suppliers) have stepped up to fill the void in supply of recycled-content resins. These companies are developing sourcing channels and quality assurances such as UL certification for recycled-content resins. To date, however, sourcing of plastic scrap is primarily from clean, post-industrial feedstreams such as manufacturing scrap and compact discs, in addition to post-consumer water bottles. Only small quantities of recovered post-consumer electronic equipment make their way back into new electronic products, principally due to quality assurance concerns and previous use of now restricted substances (e.g., halogenated flame retardants) in resins. In addition, most efforts focus on higher-priced resins such as PC and PC/ABS. With these higher-priced resins, compounders can cover their sourcing and processing costs, while offering a competitively-priced product. The potential cost savings in the purchase of recycled resins can range from 10-30 percent.

C. Molders

For molders, recycled-content resins appear to present no major processing issues. As with the introduction of any new feedstream, processing parameters must be developed to match the material characteristics and mold design, and then tweaked for optimum performance. Despite the ease of use, the molders of electronic equipment in this study noted that they use a limited volume of recycled-resins in their operations. Molders fulfill their customer's requirements, and in the case of recycled content, their customers specify little recycled-content resins. Regulatory constraints (e.g., FDA requirements), a lack of market drivers, and the

perception of design engineers that recycled resin is inferior were cited as possible reasons. This last point is not surprising since some OEMs are even reluctant to use internal regrind in the molding of parts.

D. Equipment Manufacturers

OEMs across the board have made significant progress in product design for disassembly and recycling to facilitate future plastics recycling efforts. These design efforts include, for example, the use of fewer types of plastics, coding plastic parts for material identification, the use of molded-in finishes, and the elimination of metal coatings for electromagnetic shielding. [4][13].

Numerous OEMs, including IBM, Xerox, and Hewlett Packard, have proven the performance of recycled-content resins in cosmetic applications and internal parts. However, many early efforts to incorporate recycled-content resins hit the supply "wall" due to uncertainties about quantity, quality assurance, and cost. As a result, several OEMs embarked on initiatives to remedy these supply challenges, including the development of in-house plastics processing programs and working in conjunction with suppliers and competitors to better understand and improve the supply of recycled resins and to develop alternative end use markets.

While some OEMs have backed off from plastics recycling due to supply issues, other OEMs, most notably IBM, have continued their commitment and through their determination have successfully incorporate recycled-content into new products. In 1998, IBM introduced the first computer that uses 100% recycled resin (PC/ABS) in all major plastic parts for a total of 3.5 pounds of resin per product. [14] One major contributor to IBM's success was the establishment of corporate-wide goals for the use of recycled plastic. Several other OEMs note that they have introduced products with recycled-content into limited markets, such as Europe. To be a realistic option, most OEMs agree that recycled-content cannot compromise performance and must be available at an equal or lower cost.

E. Electronics Recyclers

Plastics are definitely the "problem child" in electronics recycling. Today, recyclers must deal with products that are 10 years or older, complete with undesired characteristics such as resin variety, incompatible plastics adhered to each other, contamination (e.g., finishes, metal inserts), and no material coding of parts. Electronic recyclers for the most part rely on manual identification and sorting techniques. As a result of older products and current processing capabilities, the predominant disposal route for plastics is incineration or landfill. This should change as improved designs reach the end of life.

Some electronics recyclers are relying on alternative markets such as export markets. Export markets are able to manually process electronic plastics at lower cost due to less-expensive labor rates. In Massachusetts, a popular market for mixed plastic resins from end-of-

life electronic equipment is asphalt paving products. [15] Several other newly emerging markets such as flooring products hold promise as well.

F. Plastics Processors

Plastics processors are a diverse "group" of companies. Many plastics processors only accept single resin materials with little or no contamination, while others accept mixed electronic scrap and other durables. Plastics processors can perform just a few or a variety of services including material identification, grinding, sorting, metals separation, cleaning, paint removal, reformulation and extrusion (i.e., pelletize). Automated plastics identification and sorting technology that achieves high purity recyclate is available at a limited number of processors across the US. Research and development efforts continue to improve the efficiency and economics of handling mixed electronic waste streams.

V. Market Applications

Market applications for recycled engineering thermoplastics from used electronic equipment identified in the course of this project are shown in Figure 2. Closed-loop and open-loop applications were identified for resins of different quality. On the one extreme is asphalt paving products which utilize mixed plastic scrap, including engineering and commodity grade resins. On the other extreme is the proven performance of high quality, single resins in new housing applications.

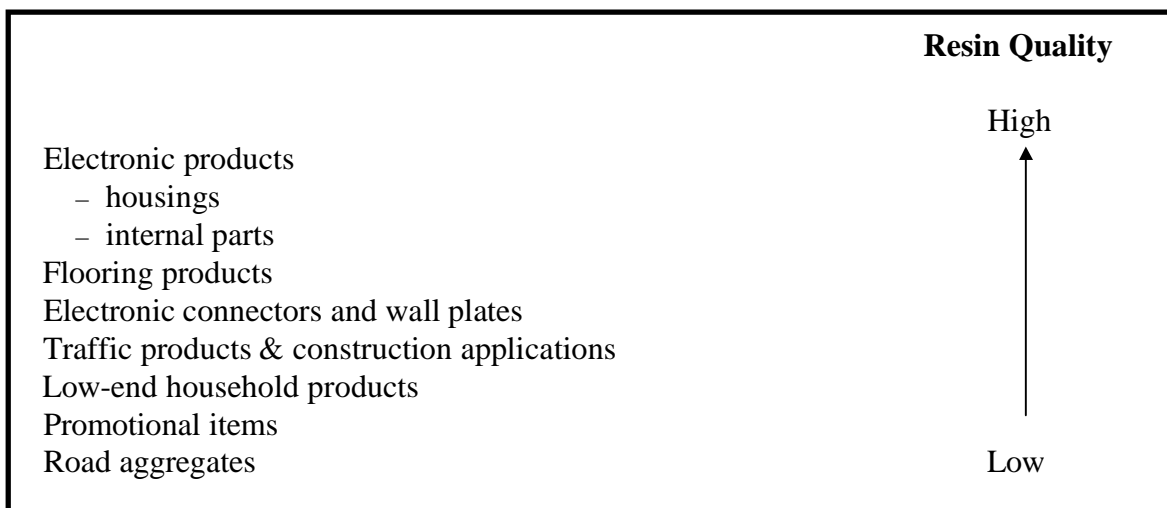


Figure 2: Sample Market Applications

VI. EPR for Electronic Engineering

The electronic product chain must work together to increase the recycling of engineering thermoplastics. It is clear from progress to date that no one link in the chain can accomplish the task alone. Table 3 applies the principles of extended product responsibility to suggest a model of shared responsibility for the electronics supply chain. It proposes roles that are within the jurisdiction of each organization, but an enhancement and appropriate extension of current functions.

Table 3: Hypothetical EPR for Plastics

Resin Suppliers	<ul style="list-style-type: none"> • Offer competitively-priced resins or team with specialty compounder to offer product
Compounders	<ul style="list-style-type: none"> • Provide quality assurances necessary to compete with prime • Increase sourcing of resins from post consumer equipment
Molders	<ul style="list-style-type: none"> • Assist OEMs in identification of opportunities to introduce recycled content and lower costs
Electronics Manufacturers	<ul style="list-style-type: none"> • Establish goals for use of recycled content in new product to demonstrate commitment and create markets for 2ndary plastics • Continued design improvements • Limit the types of plastics used • Where feasible, offer product recovery to customers to enhance consolidation of similar plastic • Extend life of plastics through reuse
Retailers & Municipalities	<ul style="list-style-type: none"> • Establish programs to collect equipment for recycling • Educate customers/constituencies about electronics recycling
Customers-Individual, Government, Institutional	<ul style="list-style-type: none"> • Timely turnover of equipment into recovery systems • Pay for recycling service, if needed, as "total" cost of ownership • Environmentally-preferable purchasing
Electronic Recyclers & Plastic Processors	<ul style="list-style-type: none"> • Continued improvements in processing technology • Process plastics to meet market needs for recycling in high end applications • Establish alternative end markets, where needed
Government	<ul style="list-style-type: none"> • Encourage industry-specific EPR partnerships, emphasizing market-based incentives & recycling infrastructure development • Use the "voice of the customer" to stimulate market change

The supply chain analysis revealed issues in both supply and demand for recycled engineering thermoplastics, creating what many observers in the industry characterize as a "chicken and egg" situation. Both resin suppliers and equipment manufacturers tested the markets, and most pulled back. As a result, commitment to recycling on the part of OEMs and resin suppliers appears to be the most pressing obstacle to further progress. For this reason, an EPR framework for the electronics supply chain needs to simultaneously address these two major issues 1) assurance of adequate volumes of consistent, quality supply; and 2) creating market opportunities and demand for the use of recycled resin. With strong market demand for recycled resins, the collection and processing infrastructure should grow and mature to meet market requirements.

Technology does not appear to be the major obstacle to plastics recycling. Much progress has been made over the last several years in identification, sorting, processing and use of recycled-content resin. Investment in available technology that can identify and sort mixed-resin, post-consumer electronics stream, however, is an issue. Such investments are difficult to justify or maintain without assurances that markets will utilize and be willing to pay the price for the recycled resin.

It is very possible that European pressures to incorporate recycled content in new products may drive some companies to further their commitment to plastics recycling, similar to the flurry of design and recycling activity stimulated by early European product take back proposals. The European Union second draft Proposal for a Directive on Waste from Electrical and Electronic Equipment (July 1998) requires new electrical and electronic equipment to contain at least 5 percent recycled plastic by January 1, 2004. Proposed recycling rates for computer equipment is a minimum of 70 percent by weight, while equipment containing CRTs must be recycled at a minimum rate of 90 percent.

Similar proposals for automobiles are driving changes in the US automobile industry. Daimler Chrysler launched a new policy in December 1998 to require plastics parts supplier to provide at least 20 percent recycled content by weight by the year 2000. By 2002, the percentage increases to 30 percent. The new standard requires that recycled-content parts not come at the expense of cost, quality, weight, delivery or performance. This new policy is a response to European pressure to make cars more recyclable, combined with DaimlerChrysler's belief that recycled content can be economically advantageous. [16]

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